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FOLIAR ANALYSES OF CONIFERS ON SERPENTINE AND GABBRO SOILS IN THE KLAMATH MOUNTAINS

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Abstract

Soils, timber site data, and the foliage of mature conifer trees were sampled at 16 Klamath Mountains sites with serpentine soils and four sites with gabbro soils. The basal areas of trees at the gabbro sites were greater than the basal areas at the serpentine sites. Tree height growth, based on old growth site curves, was significantly greater on the gabbro soils than on the serpentine soils. The main soil difference was about five times greater exchangeable Mg from the serpentine soils than from the gabbro soils. The higher Mg in serpentine soils was not reflected in higher concentrations of Mg in the foliage of yellow pine (*Pinus spp.*), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), or incense cedar (*Calocedrus decurrens* [Torr.] Florins) trees on serpentine soils, but Ca was significantly higher in the Douglas-fir tree foliage on gabbro soils. The high Mg in the serpentine soils may interfere with the utilization of Ca by Douglas-fir trees causing their foliage to have lower Ca concentrations than in the foliage of Douglas-fir trees on gabbro soils. For each of the three tree species (yellow pine, Douglas-fir, and incense cedar), foliar N, P, and K concentrations were not appreciably different on serpentine versus gabbro soils. Although soil N and P were not determined, organic matter concentrations did not differ between serpentine and gabbro soils.

Key Words: Foliar analyses, conifers, gabbro, serpentine, Klamath Mountains, soil chemistry, tree growth.

Serpentine and gabbro soils support many kinds of plants that do not grow on other kinds of soils. Many plant species are unique habitants of gabbro soils, not growing on serpentine soils or any other kinds of soils (Oberbauer 1993; Wilson et al. 2010). Most speculation about the special characteristics of gabbro soils that allow unique plants to grow on them has concentrated on the chemistry of the soils (Dayton 1966; Hunter and Horenstein 1992; Alexander 2011; Burge and Manos 2011).

The definitive relationships of unique plants to the gabbro soils on which they grow are elusive; the reasons that some plants grow only on gabbro soils are unknown. Foliar analyses might provide some clues. The elemental compositions of plant leaves depend upon many factors, including the availabilities of the elements from the soils which their roots occupy. Because plant leaf compositions commonly reflect the chemical compositions of soils in which they are growing, leaf analyses from the same kinds of plants on gabbro and serpentine soils can be compared to learn what elemental concentration differences in the plants are most representative of differences in the soils that might be responsible for growth and survival differences (Turner et al. 1978).

Although there are foliar analyses of plants growing on serpentine soils (e.g., Alexander et al. 2007), there is a dearth of comparable data for plants growing on gabbro soils. In a previous investigation of serpentine soils that included four soils on gabbro (Alexander et al. 1989), leaves were taken from conifers for foliar analyses. Data from the foliar analyses have not been published; they are a source of information that can be utilized to compare differences in the utilization of some plant nutrient elements by different conifer species on serpentine and gabbro soils. Serpentine and gabbro soils, and leaves from trees on the soils, were sampled on unmanaged forested land over the Trinity ultramafic body, or Trinity ophiolite, in the Klamath Mountains of California. Although the original interest was timber management (Alexander et al. 1989), data from analyses of the soils and conifer foliage are useful for investigating responses of the conifers to the contents of plant nutrient elements in the soils. The soils data, timber site, and basal area data were reported in Alexander et al. (1989), but the gabbro soils were not differentiated from the serpentine soils, and no foliar analyses were reported for the trees. The current objective is examination of elemental chemical analyses from conifer foliage on 16 serpentine soils and on four gabbro soils of the Trinity ophiolite to learn how differences in plant nutrient element concentrations in the foliage relate to chemical differences in the soils.

Area of Investigation

The Trinity ophiolite is a large area of predominantly serpentinized peridotite and gabbro in the eastern part of the Klamath Mountains (Fig. 1). Soils and conifer foliage were sampled at

FIG. 1. Locations of the soil and foliage sampling sites in the Klamath Mountains of California. Serpentine ecosystem sites are represented by open circles. Gabbro ecosystem sites are represented by closed circles.

FIG. 2. A moderately deep soil on gabbro that has intruded the Trinity ophiolite. Graduations on the tape are each 10 cm, and the white mark at the bottom is at 75 cm.

altitudes from 700 to 1920 m on serpentinized peridotite and from 660 to 1700 m on gabbro. The mean annual precipitation, mainly winter rain and snow, ranges from 750 to 1400 mm on the serpentine and from 1250 to 1750 mm on the gabbro soils. The soils were mostly cool (mesic soil temperature regime), moderately deep Inceptisols and Alfisols (Fig. 2), with some Mollisols on the serpentinized peridotite. They are in loamy-skeletal, fine-loamy, and clayey-skeletal families (Soil Survey Staff 1999). The overstory was predominantly yellow pine (*P. jeffreyi* Balf. on serpentine and *P. ponderosa* P. Lawson & C. Lawson on gabbro soils), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and incense cedar (*Calocedrus decurrens* [Torr.] Florins). Huckleberry oak (*Quercus vaccinifolia* Kellogg) was the most common shrub; California coffeeberry (*Fragula californica* Eschsch. subsp. *occidentalis* [Howell ex Greene] Kartesz and Gandhi) was common on both serpentine and gabbro soils, even though it is supposedly a serpentine endemic (Safford et al. 2005). Grasses, mainly fescues (*Festuca idahoensis* Elmer and *F. californica* Vasey) and wheatgrass (*Elymus spicatus* [Pursh] Gould) were common on the serpentine soils with the more open overstories and less shrub cover.

METHODS

Soils were sampled from the 0–10 and 10–30 cm depths at three locations on 0.1 acre-ft (0.04 ha) plots; samples from each depth were mixed, air-dried, and passed through a sieve to obtain *fine-earth* (particles <2 mm) for laboratory analyses. Ages and heights of representative trees were measured and basal areas were measured for all trees on each plot. Current year leaves were sampled from the lower south sides of mature yellow pine, Douglas-fir, and incense cedar trees; three subsamples from each tree group were combined for analyses.

Weight loss at 450°C (LOI, loss-on-ignition) from air dry soil was chosen as an indicator of soil organic matter. Exchangeable Ca, Mg, and K were extracted with neutral ammonium acetate and Mn, Fe, and Ni were extracted in Na citrate-dithionite solution (Alexander et al. 1989); the quantities of all cations were recorded by atomic absorption (AA) spectroscopy. Data for samples from the 0–10 and 10–30 cm depths were combined in 1:2 ratios for the current data analyses. Differences between means for each element in serpentine and in gabbro soils were compared by an unpaired test (Snedecor and Cochran 1967).

Current year foliage was dried and pulverized, N was ascertained by the micro-Kjehldahl method, and other elements were determined following perchloric acid digestion of pulverized foliage (Zinke and Stangenberger 1979). Phosphorus was ascertained by molybdenum blue colorimetry and Ca, Mg, K, and Mn by AA spectroscopy. For each conifer group and foliar element, differences between sample means for serpentine and for gabbro soils were compared by an unpaired t-test (Snedecor and Cochran 1967).

Results and Discussion

Soil and timber site data. Basal areas of the trees, and standard deviations, were 41.4 ± 11.7 m^2/ha on serpentine and 65.0 ± 9.1 m^2/ha on gabbro soils. A timber site index (TSI) that is based on the presumed heights of trees at 300 yr (Dunning 1942) and reported by Alexander et al. (1989) was significantly higher for trees on four sites with gabbro soils than for the trees on the 16 sites with serpentine soils (Table 1, unpaired t-test, $\alpha < 0.01$). The trees measured on the serpentine and gabbro soils were mostly yellow pine, some Douglas-fir, and few white fir (*Abies concolor* [Gordon & Glend.] Lindl. ex Hildebr. var. *concolor*) (C. Adamson, USDA Forest Service, 1989, now retired, personal communication).

Exchangeable Mg was much greater from the serpentine soils than from the gabbro soils, but there were no significant differences for exchangeable Ca or exchangeable K. Although gabbro soils had more dithionite-citrate extractable Cr, Mn, and Fe, only the Cr was significantly greater than from serpentine soils. The amounts of Cr reported in Table 1 are not total amounts, and toxic Cr(VI) was not differentiated from nontoxic Cr(III), which is much more common in unpolluted soils (Adriano 2001). It is unlikely that any of the first transition elements were toxic to the conifers.

Foliage analyses. The Douglas-fir and yellow pine tree data can be compared to analyses for foliage from 82 Douglas-fir and 78 ponderosa pine trees collected throughout the conifer forests of California, Oregon, and Washington (Zinke and Stangenberger 1979). Zinke and Stangenberger (1979) produced distribution curves for chemical element concentrations in the Douglas-fir and ponderosa pine tree foliage. Based on those curves, means of data from trees on the 16

Table 1. Analyses of Serpentine and Gabbro Soil Samples from 0 to 30 cm Depths. Units of measurement indicated in header. Numbers in parentheses are the standard deviations. Significant differences at the 95% ($\alpha < 0.05$) or 99% ($\alpha < 0.01$) levels of confidence are indicated by one (*) or two (**) asterisks.

Soils	n	TSI (ft)	LOI (g/kg)	Ca (mmol+/kg)	Mg (mmol+/kg)	K (g/Mg [ppm])	Cr (g/Mg [ppm])	Mn (g/Mg [ppm])	Fe (g/Mg [ppm])	Co (g/Mg [ppm])	Ni (g/Mg [ppm])
Serpentine	16	102(19)	67(23)	64(31)	218(79)	3.1(1.2)	0.19	12.3	56	0.06	0.86
Gabbro	4	146(7)	76(15)	65(8)	41(10)	2.4(0.8)	0.3	21.2	76	0.08	0.6
t, 18 df.		14.8**	0.64	0.04	4.39**	0.97	2.11*	1.87	1.07	0.64	0.84

TABLE 2. COMPARISONS OF ELEMENTAL CONCENTRATIONS IN FIRST YEAR YELLOW PINE (PONDEROSA AND JEFFREY PINES) AND DOUGLAS-FIR NEEDLES FROM THE SOILS ON THE TRINITY OPHIOLITE IN THE KLAMATH MOUNTAINS. Numbers in parentheses are percentiles based on foliar analyses from 78 ponderosa pine and 82 Douglas-fir trees in a variety of habitats (Zinke and Stangenberger 1979). Significant differences at the 95% ($\alpha < 0.05$) or 99% ($\alpha < 0.01$) levels of confidence are indicated by one (*) or two (**) asterisks.

Tree and substrate	n	N (g/kg [ppt])	P (g/kg [ppt])	Ca (g/Mg [ppm])	Mg (g/Mg [ppm])	K (g/Mg [ppm])	Fe (g/Mg [ppm])	Mn (g/Mg [ppm])
Yellow pine							*	
Serpentine	13	10.6(48)	1.44(67)	1.23(36)	1.52(95)	6.64(58)	37(24)	72(37)
Gabbro	4	10.2(39)	1.40(64)	1.49(41)	1.64(98)	5.96(45)	42(29)	182(77)
Douglas-fir			**				**	
Serpentine	13	9.0(18)	1.53(63)	2.02(13)	1.94(84)	8.15(79)	76(8)	117(23)
Gabbro	4	9.4(22)	1.24(42)	3.99(61)	2.53(95)	7.09(63)	57(1)	505(93)
Incense cedar							**	
Serpentine	13	9.5	1.17	8.18	3.88	5.88	76	34
Gabbro	3	9.0	0.96	8.57	3.15	6.88	83	72

serpentine and four nonserpentine soils (gabbro) in the Klamath Mountains investigation were given percentile ratings, which are in parentheses in Table 2. Foliar Douglas-fir N was very low on serpentine soils (18th percentile, indicating that only 17% of the trees in the 82-tree sample had lower foliar N contents), and Douglas-fir foliar N was low on gabbro soils (22nd percentile); but N was only marginally low (percentile <50) in yellow pine foliage on both kinds of soils. Magnesium was very high in foliage from all of the yellow pine and Douglas-fir trees and Ca was relatively low in the foliage of Douglas-fir trees on serpentine soils. The lower Ca in foliage of Douglas-fir trees on serpentine soils, compared to the trees on gabbro soils, is reflected in Figure 3, where the Douglas-fir foliage Ca concentrations for three trees on gabbro soils are shown nearer to the Ca apex (higher Ca) than the Douglas-fir foliage Ca contents of trees on serpentine soils.

Higher Mn concentrations in the foliage of trees on gabbro soils than in the foliage of trees on serpentine soils (Table 2) was related positively to higher exchangeable Ca/Mg ratios for the gabbro soils ($\alpha < 0.01$) and to higher timber site index on them (Alexander et al. 1989), rather than to differences in the contents of Mn extractable from soils. Exchangeable Ca was about the same from both serpentine soils (64 mmol+/kg mean) and gabbro soils (65 mmol+/kg mean), but exchangeable Mg was significantly greater ($\alpha < 0.01$) from serpentine soils (218 mmol+/kg mean) than in gabbro soils (41 mmol+/kg mean); consequently, the Ca/Mg ratios were greater in gabbro soils (Alexander et al. 1989). The significantly lower Ca in Douglas-fir foliage from trees on serpentine soils, compared to trees on gabbro (Table 2) may be a result of significantly higher Mg in serpentine soils inhibiting the uptake of Ca from the soils. Foliar Mg, and especially Ca, were considerably higher in the incense cedar foliage than in the yellow pine and Douglas-fir trees, but Zinke and Stangenberger (1979) had no probability distributions for foliage from incense cedar trees.

CONCLUSIONS

The growth of coniferous trees is considerably greater on gabbro soils than on serpentine soils. High Mg in serpentine soils appears to be the main limitation of tree growth of serpentine soils. The high Mg may inhibit the utilization of Ca, which is evident in the higher concentration of Ca in the foliage of Douglas-fir trees on gabbro than in foliage of Douglas-fir trees on serpentine soils. Most of the first transition elements from Cr to

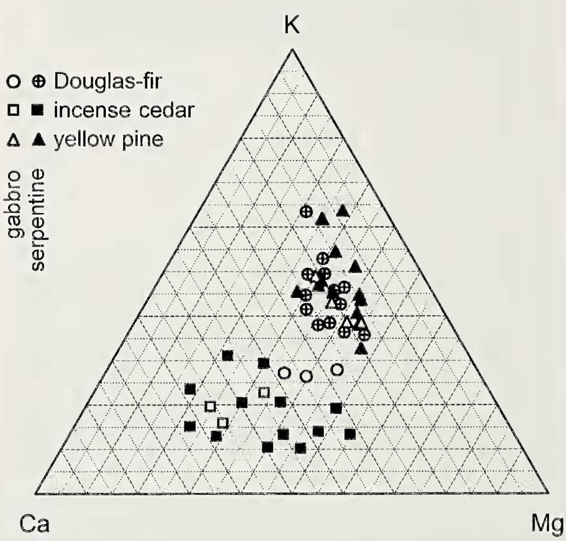

FIG. 3. The proportions of Ca, Mg, and K ions in Douglas-fir, yellow pine, and incense cedar foliage from trees on the Trinity ophiolite of the Klamath Mountains. Data for the trees on serpentine soils are represented by closed symbols (cross hatched circles, triangles, and squares). Data for the trees on gabbro soils are represented by open symbols (circles, triangles, and squares). Apices of the triangle represent 100% K (top), Ca (left), and Mg (right).

Ni, which are sometimes toxic to plants, had higher concentrations in dithionite-citrate extracts from gabbro soils than from serpentine soils, but there was no evidence that any of these elements were toxic to the trees. None of the comparisons of the N, P, or K concentrations in yellow pine, Douglas-fir, or incense cedar foliage for trees on serpentine and gabbro soils revealed any significant differences between soils. If the serpentine soils contain less N and available plant P than the gabbro soils, the differences are not reflected in the foliar analyses.

The significantly greater Ca in Douglas-fir tree foliage on gabbro soils than on serpentine soils is a clear distinction related to the differences between the different soils. Although the foliar Ca differences between the soils were not significant for yellow pine and incense cedar trees, the results for Douglas-fir trees indicate that foliar analyses of plants can reveal interesting clues about the effects of gabbro soils on the plants.

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